# Drone Cage Design and Implementation to Enable Small Drone Architecture Testing

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## Abstract

Geometric mechanics is a dynamical formalism that allows for simultaneous treatment of rotational and translational motion without the drawbacks of attitude parameterization sets. While geometric mechanics is well suited to deal with full six degree-of-freedom motion or significant position-attitude coupling, this formalism has yet to be extensively applied to hardware systems. The broader research goals of this work aim to prove the practical viability of this theoretical framework by applying it to a class of Crazyflie drones, which are frequently used to assess Guidance, Navigation, and Control schemes. To efficiently achieve these goals, a reliable, collapsible drone cage is required to conduct such experiments in. As a result, the team has designed and constructed a modular cage that can be used to safely test drone behavior. Requirements from the drones' suite of hardware necessitate a cage with dimensions of 3m x 3m x 7m, a fact which drove the collapsible nature of the design. Given the cage's modularity, its size can be further scaled for future experiments. The work here discusses the construction and development methodology of the cage, illustrating how the cage and Crazyflie hardware interface to provide accurate truth-data.

## Hardware

- This research implements the use of the following hardware:
  - Over twenty Crazyflie 2.0 drones (Fig. 1)
  - Bitcraze Locopositioning decks
  - Two Khepera IV ground vehicles (Fig. 1)
  - Foxeer FPV Cameras
  - FPV Transmitters and Receivers
- The Locopositioning decks drove the dimensions for the overall size of the cage (Fig. 2)

**Figure 1:** Khepera IV and Crazyflie Drones

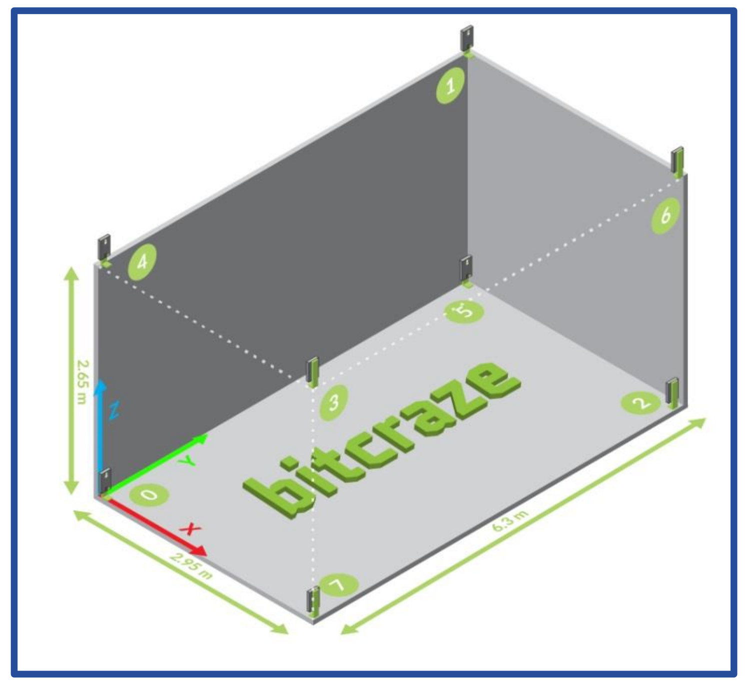


**Figure 2:** Bitcraze Cage Sample Setup

## Methodology

- For a cage of 3m x 3m x 7m, the scale of the manufacturing process is large. As such, expediting the construction and assembly procedure was of key importance. The work-flow is given in Figure 3.
- In each step, assessment of the bottleneck was pivotal in accomplishing the tasks in a timely manner. The bottlenecks and their causes are given in Table 1. Having a knowledge of these bottlenecks was vital in assigning work to additional volunteers.
- Keeping the bottlenecks in each stage contained and functioning at capacity proved to be effective at keeping people working before and after the bottleneck. This combination was effective in maintaining constant progress. A 1m x 1m x 1m module rendering is shown in Figure 4.

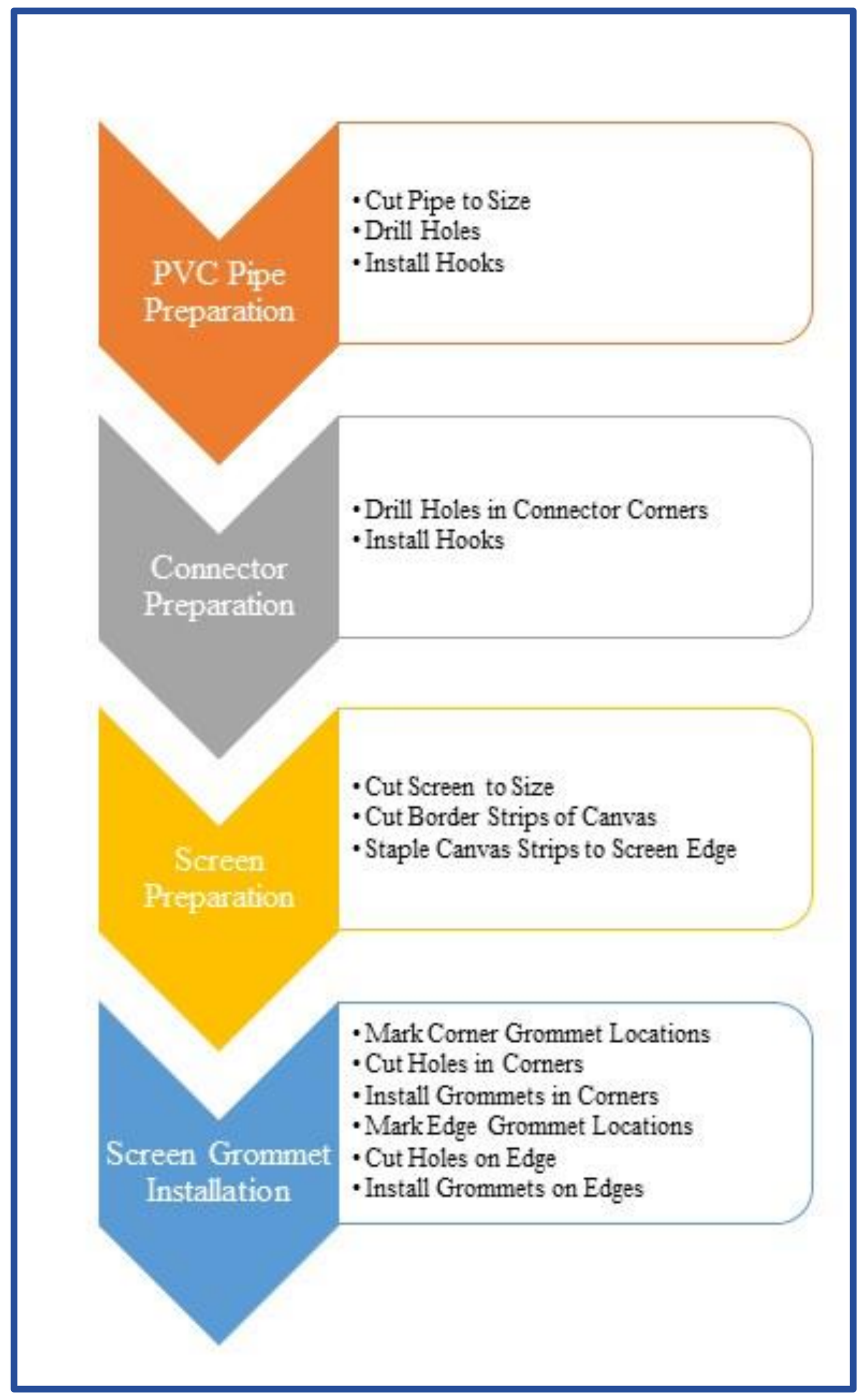


**Figure 3**: Assembly Work-Flow

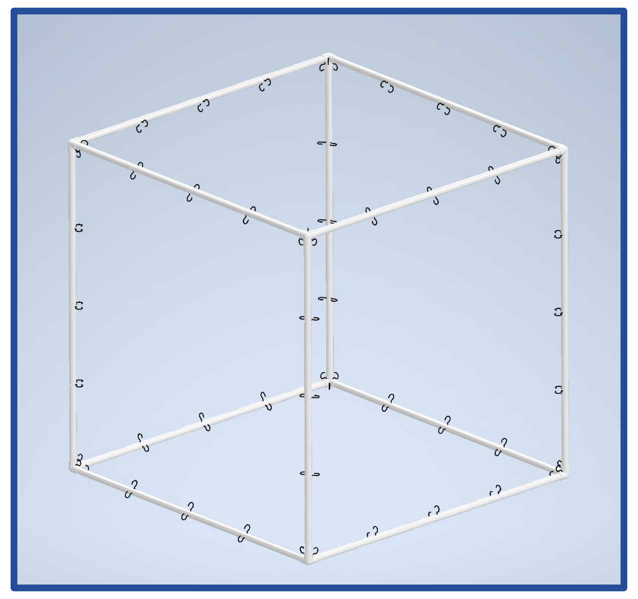

**Figure 4**: Single Cage Module

**Table 1**: Assembly Bottlenecks and Causation

| Assembly Process Stage | Bottleneck | Cause |
|---|---|---|
| PVC Pipe Preparation | Drilling Holes | Number of Drills |
| Connector Preparation | Drilling Holes | Number of Drills |
| Screen Preparation | Cut Screen To Size | Number of Cutting Surfaces and Available Cutting Space |
| Screen Grommet Installation | Grommeting | Number of Grommet Tools |

## Results

- Cage is viable for small drone testing and applicable to a variety of experiments
- CAD renderings of the cage parts are shown in Figures 5-7.
- Render of full 3m x 3m x7m cage is given in Figure 8.
- A 2m x 2m x 2m Iteration of the Overall Cage is shown in Figure 9.

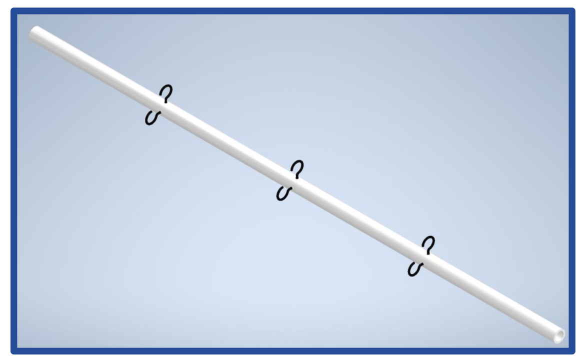

**Figure 5**: Cage Edge Rendering

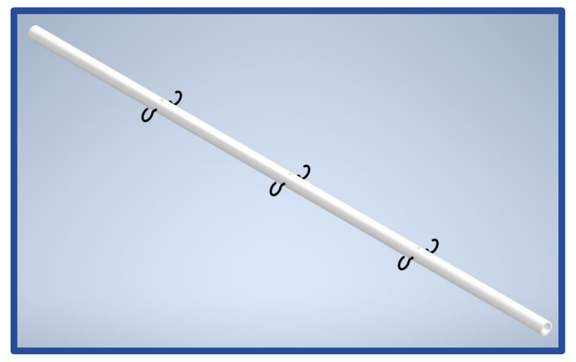

**Figure 6**: Cage Edge Rendering

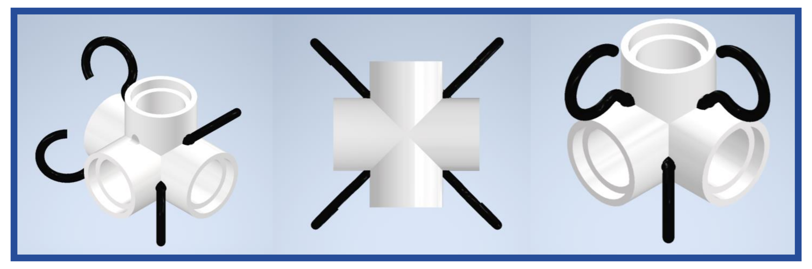

**Figure 7**: Cage Connector Corners Rendering

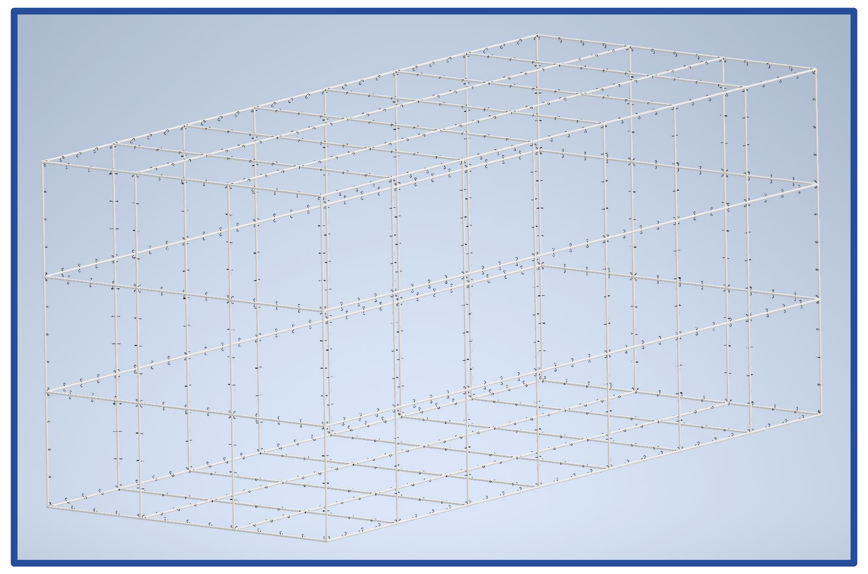

**Figure 8**: Final Cage Rendering

**Figure 9**: 2m x 2m x 2m Cage

## Future Developments

Completion of this cage will enable the following experiments:

- Experimental validation of the Lie Group Variational Filter
- Map Building within SE(3) Framework
- Data Collection and Hazard Detection and Avoidance
- Simple Landing Control with Topography Data
- Landing Optimization on the Special Euclidian Group
- Udwadia-Kalaba Formulation Extensions for Landing Optimization
- Target State Estimation
- UK Formulation Applied to 3D Modeling
- Stochastic Target Tracking
- Adversarial Controlled Stochastic Target Tracking
- Vision Based Adversarial Controlled Stochastic Target Tracking